Measurement of Finite Extensibility Parameters for Polymer Solutions

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ABSTRACT

We consider the stretching of a liquid filament formed by a polymer solution. A liquid bridge is kept between two circular disks. The upper plate is fixed while the lower plate falls due to gravity. The experiment was originally described by Matta & Tytus[1]. The magnitude of the gravitational force pull depends on the mass attached to the lower plate. Hence, by changing mass we can explore the viscoelastic nature of the fluid. It appears that with an optimal choice of mass the polymer solution is rapidly stretched and the finite extensibility limit is reached. This chacteristic behaviour is clearly observed from measurements of the time dependent filament diameter. Based on theoretical analysis and numerical simulations of a FENE type model fluid we develop a simple expression for the finite extensibility parameter and explore the stretch relaxation following full extension of the polymer chains. The developments presented here draws on the work of Szabo et al.[2].

EXPERIMENTAL OBSERVATION

A uniform cylindrical liquid bridge of length L_0 is positioned between a fixed plate and a weight having mass m. At some initial time t_0 the weight is released and starts falling due to gravity. In Fig.1 a sketch illustrates the filament geometry after release of the weight. The aspect ratio Λ is defined by L_0/R_0 where R_0 is the initial uniform filament radius.

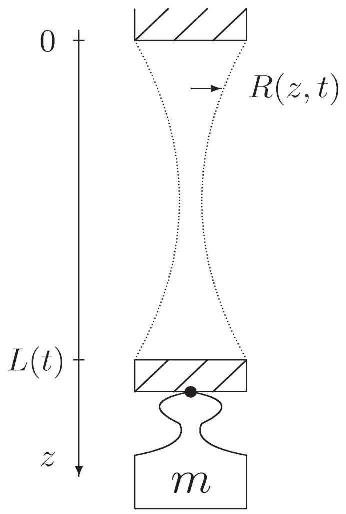

Figure 1. Sketch of filament geometry.

In our experiments we monitor the mid-filament diameter as function of time. In Fig. 2 we show data from four experiments with different loads (1.8g, 2.8g, 5.8g and 20.8g). The fluid used in the study consisted of a poly(styrene) standard with a molecular weight of M_w = $2.84\cdot10^6$ g/mol and a polydispersity of P = 1.13 (obtained from Polymer Standard Services, Ontario, NY) dissolved in styrene oligomers (Picolastic A5 Resin) at a concentration of c_w = 0.025 wt% (so-called Boger fluid). The zero-shear viscosity of this fluid was determined with a rotational rheometer (AR2000, TA Instruments) to be $\eta_0 = 92$ Pas. In addition, a linear viscoelastic characterisation yielded a longest relaxation time of $\lambda = 24.8$s and the solvent viscosity $\eta_s = 86.5$ Pa s.

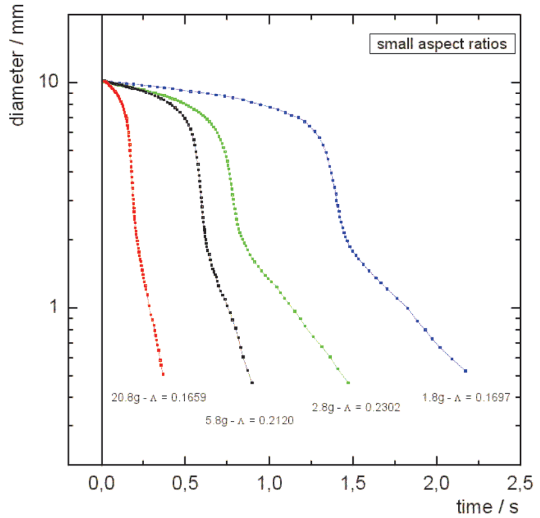

Figure 2. Diameter vs. time for different loads (Data from Szabo et al.[2]).

The initial aspect ratios are rather small; of the order $\Lambda = 0.2$. We observe a characteristic behaviour in which the diameter of the filament thins increasingly rapidly due to the constant force imposed by the falling cylindrical weight, but then at a critical point in time there is a change in slope and the thinning process deviates from the expected Newtonian behaviour (see Szabo et al.[2] for comparison). Depending on the load the transition appears at different times. We note, however, that the transition seems to occur at a characteristic filament diameter. This observation has initiated the theoretical developments described in Szabo et al.[2]. Based on the so-called FENE-P viscoelastic model (see Bird et al.[3] for reference) a uniform filament model lead the an estimate for the characteristic finite extensibility parameter b:

$$b_{experimental} = (R_0/R_{characteristic})^4$$

From the data presented in Fig. 2 we may calculate a b-value of approximately 800. In Fig. 3 we compare a numerical simulation using the b-value estimate with experimental data.

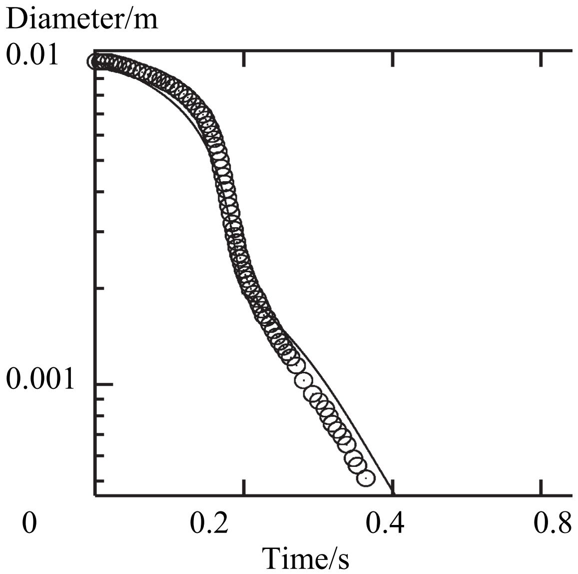

Figure 3. Diameter vs. time. Experiments compared to numerical simulation for b=800 (m=20.8g). (Data from Szabo et al.[2]).

REFERENCES

1. Matta, J.E. and Tytus, R.P. (1990), “Liquid stretching using a falling cylinder”, *J. Non-Newtonian Fluid Mech.*, **35**, 215-229.

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3. Bird, R.B., Armstrong, R.C. and Hassager, O., *Dynamics of Polymeric Liquids. Volume 1: Fluid Mechanics.* John Wiley & Sons, New York, 2nd ed., 1987.